Ka-Band, MEMS Switched Line Phase Shifters Implemented in Finite Ground Coplanar Waveguide

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Abstract: Ka-band MEMS switched line one and two-bit phase shifters implemented in finite ground coplanar waveguide on High Resistivity Silicon (HRS) substrates are presented. The phase shifters are constructed of two single-pole double-throw (SPDT) switches with additional reference and phase offset transmission line lengths. The MEMS devices are doubly anchored cantilever beam capacitive switches with inductive sections (MEMS LC device); device actuation is accomplished with a 30-volt peak-to-peak AC square wave. The one and two-bit phase shifters have a minimum insertion loss (IL) and a maximum return loss (RL) of 0.85 dB and 30 dB and 1.8 dB and 25 dB respectively. The one-bit phase shifter's designed phase shift is 22.5° and actual measured phase shift is 21.8° at 26.5 GHz. The two-bit phase shifter's designed phase shift is 22.5°, 45°, and 67.5° and the actual measured phase shifts are 21.4°, 44.2°, and 65.8°, respectively, at 26.5 GHz.

INTRODUCTION

RF and microwave communication systems rely on frequency, amplitude, and phase control circuits to efficiently use the available spectrum. Phase control circuits are required for electronically scanning phased array antennas that enable radiation pattern shaping, scanning, and hopping. Conventional phase shifters use GaAs MESFET and PIN diode switches; however, these devices have high insertion loss and appreciable DC power consumption. Replacing traditional semiconductor based phase shifters with MEMS based phase shifters has several advantages, including negligible power consumption, high linearity, low insertion loss, and improved isolation. Distributed [1], switched line [2,3], and reflection mode [4] phase shifters utilizing MEMS devices integrated into microstrip transmission lines have been reported with low loss.

Here, we present the design, fabrication, and measured characteristics of the first two bits of a Ka-band, MEMS four-bit switched line phase shifter utilizing Finite Ground Coplanar (FGC) waveguide under development at NASA Glenn Research Center. The single-bit phase shifter is designed for a phase shift of 22.5° and the two-bit phase shifter is designed for phase shifts of 22.5°, 45°, and 67.5°. The phase shifters are composed of two single-pole double-pole (SPDT) switches with additional reference and offset phase transmission line lengths to achieve the phase shifting characteristics of the device.

MEMS LC SHUNT DEVICES

The MEMS switches embedded within the switched line phase shifters are doubly anchored cantilever beam capacitive shunt devices with inductive sections, referred to as MEMS LC switches [5,6,7], as depicted in Figure 1. Together, the capacitance sections and inductive segments transforms the MEMS structure into a resonant device capable of creating a short circuit to ground over a wide frequency range through the simple adjustment of the dielectric thickness or the inductor layout. The cantilever beam is 650 µm long and 175 µm wide and consists of three capacitive sections separated by two high inductive segments. As seen in Figure 1, finite ground coplanar waveguide (FGC) is used as the transmission line media for the MEMS LC devices as well as the SPDT switch and the switched line phase shifters described herein. The center strip width (S), the slot width (W), and the ground plane width are 80, 50, and 220 µm, respectively. The planar configuration of the FGC transmission line makes it possible for the MEMS LC device to be placed in a shunt configuration with the cantilever having negligible effects when the device is in the OFF-state (up-position) and then resonate at the specific design frequency when in the device is in the ON-state (down-position). Furthermore, the narrow width of the FGC transmission lines enable the MEMS cantilever to extend over the entire transmission line with no physical contact between the cantilever and the FGC. This enables the MEMS bias to be applied to the cantilever itself while the FGC line is held at ground or a small potential required to bias other electronic components. Lastly, FGC lines have low dispersion, low attenuation, do not require via holes, and are compatible with flip-chip interconnects.

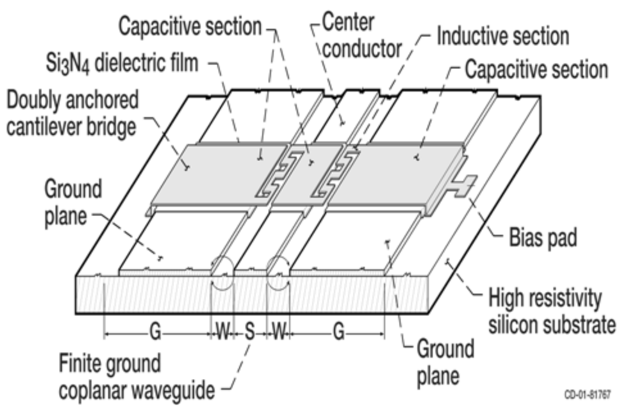

Figure 1. MEMS LC shunt device.

Silicon Nitride (Si_3N_4) with a dielectric constant of 8.5 and thickness of 900 Å is used for the insulator between the upper and lower plates of the LC MEMS switch. The doubly anchored bridge and FGC is fabricated on silicon substrates with a resistivity of 2500 Ohm cm using standard IC processing and Au plating procedures. The thickness of the gold plated bridges is 1.7 μm with a height of approximately 4 μm. The MEMS structure shown in Figure 1 as well as the SPDT switch and the switched line phase shifters were characterized with an HP 8510C Vector Network Analyzer (VNA) and Multical calibration software developed by the National Institute of Standards and Technology (NIST). The MEMS device requires a 30-volt peak-to-peak AC square wave signal to achieve actuation. The results of the MEMS LC structure have been reported [7]. The MEMS LC device has an IL, RL, and Isolation of 0.11 dB, 22 dB, and 45 dB, respectively.

MEMS SPDT SWITCH

The SPDT switch is a 3-port device with two LC MEMS structures placed a quarter-wavelength from the center of the T-junction as shown in the Figure 2. Distancing the MEMS LC devices a quarter wavelength from the center of the T-junction enables the virtual short realized from MEMS actuation to be transformed to an open at the T-junction, thus blocking nearly all the signal from passing to that port. The LC MEMS structures and the $\lambda/4$ sections are both designed to resonate at the design frequency of 26.5 GHz. The measured results for the SPDT switch are shown in Figures 3 and 4. The SPDT has a minimum IL, maximum RL, and maximum isolation of 0.3 dB, 40 dB, and 50 dB, respectively.

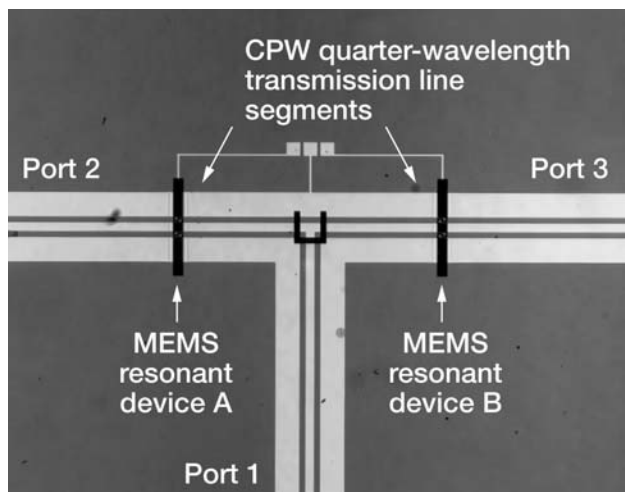

Figure 2. Microphotograph of MEMS SPDT switch.

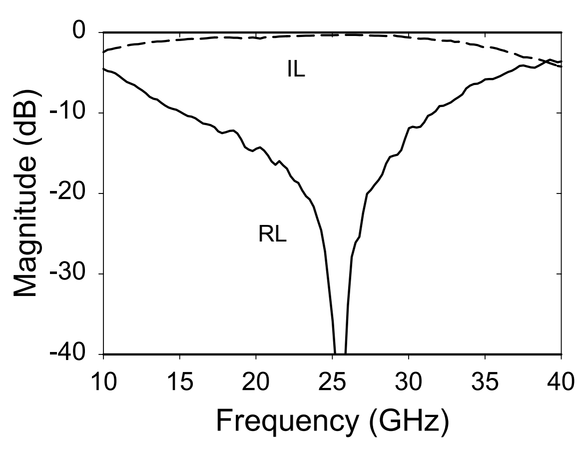

Figure 3. Measured response of MEMS SPDT switch: Device B only is activated and port-3 terminated into a 50Ω load.

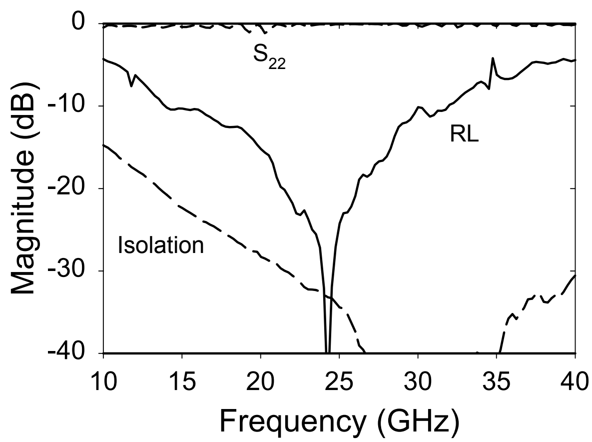

Figure 4. Measured response of MEMS SPDT switch: Device A activated only and port-3 is terminated into a 50Ω load.

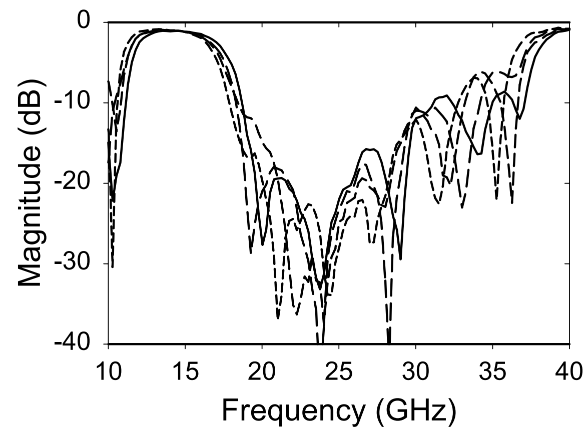

Figure 6. Measured RL of the 4-states of the two-bit switched line phase shifter.

MEMS SWITCHED LINE PHASE SHIFT

The switched line phase shifters consists of two SPDT switches with additional reference and offset phase FGC transmission line lengths as illustrated in Figure 5. The one-bit phase shifter has a phase shift of 22.5° while the two-bit has phase delays of 22.5º and 45°. Thus the two-bit phase shifter can achieve a phase shift of 0°, 22.5°, 45°, and 67.5°. The measured RL for the 2-states of the one-bit phase shifter is better then 25 dB, the measured IL for the 2-states is 0.85 dB, and the measured phase shift is 21.8°. The measured RL and IL for the 4-states of the two-bit phase shifter are shown in Figures 6 and 7, respectively.

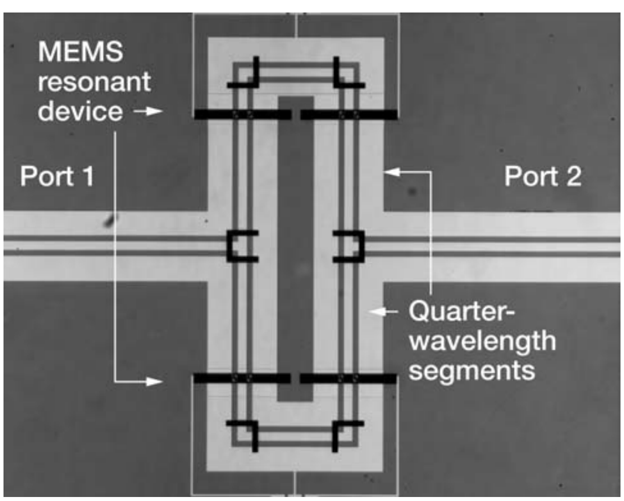

Figure 5. Microphotograph of one-bit switched line phase shifter.

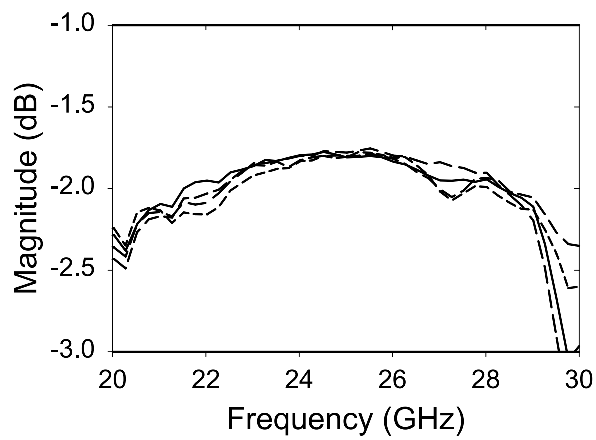

Figure 7. Measured IL of the 4-states of the two-bit switched line phase shifter.

The two-bit switched line phase shifter has a RL better than 20 dB from 20 to 27 GHz and an IL of 1.8 dB with a 0.2 dB deviation from 22 to 27 GHz for the 4-states. The phase shift for the 4-states is shown in Figure 8. The measured phase shift is 21.4°, 44.2°, and 65.8° at 26.5 GHz.

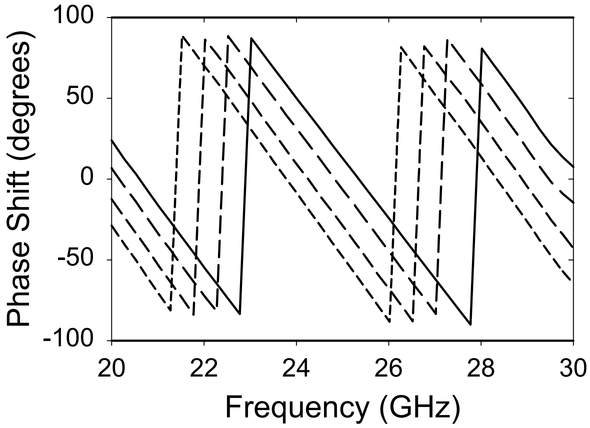

Figure 8. Measured phase shift of the 4-states of the two-bit switched line phase shifter.

CONCLUSION

One- and two-bit switched line phase shifters have been presented in this paper. The phase shifters are part of an ongoing effort to build a four-bit phase shifter for space and satellite communication systems. The phase shifters are implemented in finite ground coplanar waveguide transmission line media and are constructed from two MEMS based SPDT switches with additional reference and phase offset transmission line lengths to realize phase control operation. The one- and two-bit phase shifters have a RL better than 20 dB and an IL of 0.9 dB and 1.8 dB, respectively. The one-bit phase shifter was designed for a 22.5 phase shift and achieved a measured response of 21.8°. The two-bit phase shifter was designed to achieve a 22.5°, 45°, and 67.5° phase shifts and a measured response of 21.4°, 44.2°, and 65.8° was realized, respectively. Although the measured characteristics are very good, they can be improved by correcting for parasitic reactance at the T-junction that caused a slight shift from the design frequency.

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